Radio communications at frequencies below 10kHz

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AT the ITU conference on frequency allocations in Geneva in 1959, the frequencies below 10kHz and above 40GHz were left unallocated. The upper limit was extended at a more recent conference on space communications to 275GHz but the lower end of the spectrum has still remained unallocated. Contrary to popular opinion, the extreme bottom end of the spectrum has definite practical applications in long-distance communications and navigation systems. Already operational in the 10 to 14kHz region is OMEGA, an extremely accurate long-distance hyperbolic navigation system enabling worldwide determination of position with remarkable accuracy. For a long time the vlf region between 14 and 30kHz has been used for worldwide long-distance communication with ships, and with submarines just beneath the surface. During the past decade or so, much work has been done to evolve a system capable of maintaining communication with deeply submerged submarines, and progressively lower frequencies have been considered to overcome the exponential attenuation with frequency (the skin effect). As the frequency is lowered the attenuation suffered by a signal passing through rock or seawater decreases. Another bonus gained by using extremely low frequencies (e.l.f.) is that the D layer and earth's surface form an imperfect waveguide and permit signals to propagate worldwide with extremely low attenuation. However, at such low frequencies the efficiencies of the transmitting aerials becomes very low unless colossal structures are erected. Furthermore, the available bandwidth becomes narrower, restricting the forms of modulation that can be transmitted.

In addition to submarine communication the e.l.f./vlf spectrum has also been investigated by national governments interested in nuclear bomb-proof communications between deeply-buried underground headquarters. At extremely low frequencies certain rock strata have propagation characteristics not unlike that of the ionospheric waveguide mentioned above, and an e.l.f. signal injected into such a layer would propagate for long distances with low attenuation. Little or no signal would escape from the underground rock waveguide, making the path extremely secure and unjammable. However, discontinuities in the rock structure (for example, faulting) act as partial shorts in the waveguide and would cause considerable signal attenuation. In practice such a system could only be used where the continuity of the rock strata between underground centres was guaranteed.

Papers have also been written describing communication through the earth or sea by means of dc signalling, although if information is to be passed then the frequency ceases to be dc. Similar systems at frequencies up to 3kHz have been described for emergency communications in mines and caves. Due to the aerial inefficiency, the main mode of communication ceases to be by radiation and relies instead on conduction and induction fields (earth mode communication).

Worldwide communication at e.l.f. depends on being able to inject sufficient radiated energy into the earth-ionosphere waveguide to provide enough detectable signal at the end of the path to decode the signal. Due to the inefficiency of the transmitting aerial, colossal powers are required to produce the one watt or so that is actually radiated. This rules out any hope of amateur worldwide dx communication at such frequencies, should an amateur band ever be allocated in the e.l.f. part of the spectrum. However, if the available power is more modest, say up to 100W, communication can be achieved at these frequencies over local distances by conduction or induction fields, and there is much scope for interesting experimental work. The case for a small amateur allocation at e.l.f. when this portion of the spectrum is divided up, possibly at the next ITU frequency allocating conference in 1979, is a fairly strong one and deserves some consideration.

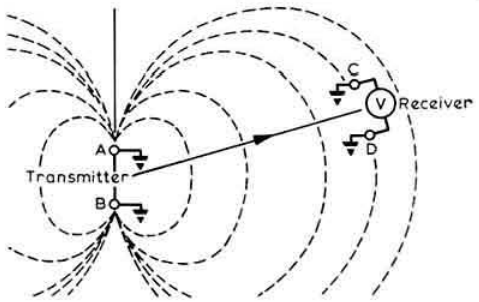

Fig 1. Principle of short-range e.l.f. communication systems

An e.l.f. earth mode communication system

The principle involved in relatively short-range e.l.f. communication systems is remarkably simple and is illustrated in Fig 1. Current is injected into the earth or water at the transmitter terminals AB and the induced conduction and induction fields are detected at the receiver as a potential difference between two grounded electrodes CD. The received signal is a function of geometry, injected current from the transmitter and the characteristics of the conductive medium between all the terminals. When radiation is neglected, and this cannot be done when the power injected is very large as in the dx systems described earlier, then the received electric field can be expressed by:

$$E_{\text{Radial}} = \frac{Ib(\cos A)k_{\text{R}}}{3{\cdot}14r^3} \qquad (1)$$

$$E_{\text{Tangential}} = \frac{Ib(\sin A)k_{\text{T}}}{6{\cdot}28r^3} \qquad (2)$$

where I is the current injected at the transmitter, b is the distance between the transmitter electrodes, r is the distance between transmitter and receiver, k_{R} and k_{T} are complex

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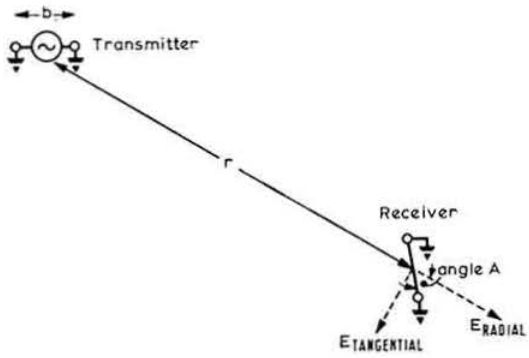

Fig 2. Orientation of transmitter and receiver

functions of the apparent resistivity and A is the angle in Fig 2 between transmitter and receiver. k_R and k_T are dependent on many factors, including frequency, but at e.l.f. they approximate to the intrinsic resistivity of the medium. The intrinsic resistivity can vary widely, but some typical values are given below:

Seawater 0·25Ω/m
Clayey sand 50Ω/m
Limestone 5,000Ω/m

From equations (1) and (2) it can be clearly seen that the range of earth mode communication systems is severely limited by the inverse cube factor. Signals are therefore attenuated rapidly with distance and this puts practical limits on low-power systems, usually of the order of one or two miles.

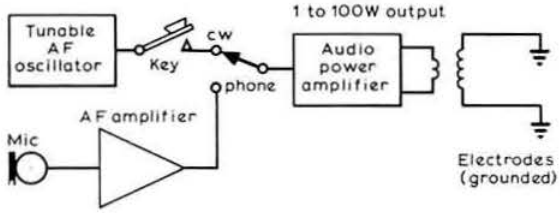

Fig 3. E.L.F. earth mode transmitter

A suitable transmitter is illustrated in Fig 3 and comprises an audio oscillator followed by an audio power amplifier suitably matched into the load presented by the two grounded "aerial" rods driven into the ground some distance apart. The receiver at its simplest is just a pair of headphones connected to two similar ground rods as far apart as possible. AC hum at 50Hz and its harmonics will almost certainly be a problem when the receiver earth rods are a moderate distance apart. A more sophisticated receiving station (Fig 4) would include narrow-band filters to reduce this problem and also cut down naturally-occurring wideband noise which is mainly of atmospheric origin. Typical noise sources are whistlers and tweeks, both generated by lightning discharges, and chorus, which is thought to be generated by electron movement along magnetic field lines.

The ultimate range will depend on the signal-to-noise ratio that is acceptable. Very slow information rates with extremely narrow band filters, such as resonant reeds, would significantly increase the range achievable. Even with bandwidths suitable for 12wpm cw, the range will still be very useful for local experiments. Phone can be used over much shorter but nonetheless useful distances, with signal-to-noise ratio again being the main constraint.

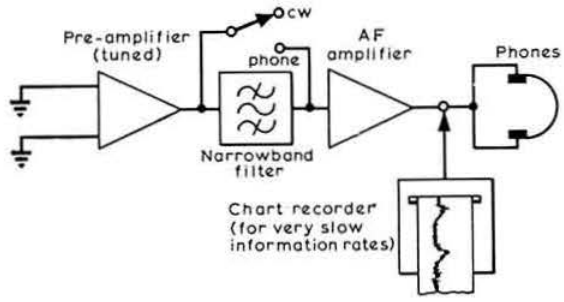

Fig 4. E.L.F. earth mode receiver. More complex receivers might include non-linear processing to reduce non-Gaussian impulsive noise spikes

The geometry of the transmitting and receiving "aerial" rods will depend on what other metal objects are buried nearby. Cables and metal pipes will cause the field patterns to become skewed and the received signal in urban areas will be almost incalculable because of this. In general, the size of the rods or earth terminals should be as great as possible and the separation of these at the transmitter end and at the receiver end respectively should be as far as possible. Using metal water pipes as one of the earth connections at each end of the link may help in some cases.

Interesting propagation tests could be carried out along a river or seacoast (Fig 5), attaching one of the transmitter and receiver "aerial" rods to a buoy in the water and burying the other rods at each end in the soil or sand. In the seacoast case especially, the propagation is similar to a lossy conductor and the achievable range may be surprising.

Other experiments could include the use of resonant loops at the receiver, instead of rods, to sense the induced field.

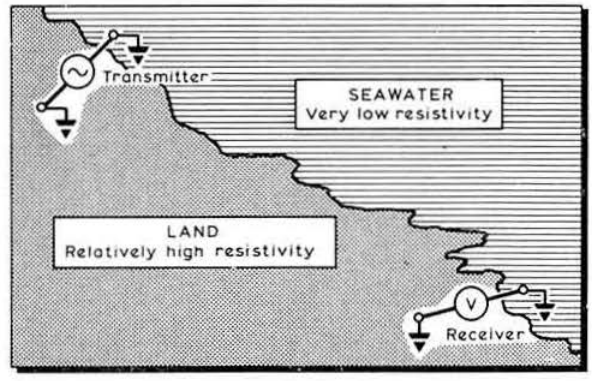

Fig 5. Suggested seacoast e.l.f. communication experiment

This technique is widely used to trace buried cables and piping. There are indeed many lines of experimentation possible.

Licensing

At present the legality of such systems is a little unclear, but the Home Office will issue Testing and Development (Radiating) Licences in the G9 . . . series to those interested in serious experimental work. The use of earth mode communications at e.l.f. for non-experimental links is not covered by such licences. If sufficient people were interested, it might be possible to get an extension of the Amateur Sound A licence to cover a small section of the e.l.f. spectrum. Such official authorization might stimulate publication of results and activities by local groups and some interesting co-ordinated experimental work could result. Internationally, now is the time to give some thought to a possible application for an e.l.f. amateur band if this part of the spectrum should be allocated at the ITU conference in 1979.

Conclusions

The spectrum below 10kHz is far from being a forgotten territory and is the centre of much attention in the communications world at the present time. Amateurs should not ignore its potential as an area for experimental work requiring little equipment to get started and presenting a subject with a difference to work on. The references below are recommended reading for all interested in the area of e.l.f./vlf communication and the first one listed in particular makes fascinating reading for those left who believe radio ends at the top end of long wave!

Acknowledgements

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BOOK REVIEW

THE RADIO AMATEUR'S HANDBOOK (1975 edition) by the headquarters staff of the ARRL. 704 pages, copiously illustrated and with many tabulations. Obtainable from RSGB, 35 Doughty Street, London, WC1N 2AE. Price £4.50 (hardback) or £3.60 (paperback) inclusive of postage and packing.

The well-known *Handbook*, having passed the four and a half million mark in half a century, is issued several months earlier this year to make its appearance more closely related to the peak of amateur activity.

There are many revisions and new designs despite the very considerable changes in the contents in recent editions, and the newly-added material not only reflects modern technique, but impresses by its practicality.

There is an attractive solid-state rf preamplifier design for 10 and 15m, with a gain of about 14dB, which would revitalize the output from old receivers. Also included is an audio bandpass filter for cw or ssb, which is useful for hum and hiss rejection. It is of special interest to those who use hi-fi headphones, which have certain disadvantages when used in amateur communication work. The filter has been named the Crud-o-ject (Continuous Random Unwanted Disturbances) and the cw version has a centre frequency of 600Hz, an input and output impedance of 600Ω, insertion loss of about 2dB, and output power limited to some 24mW. The phone version has a pass-band of 355–2,530Hz at the 3dB points. It is a passive device, so it needs no batteries, and these filter circuits have many advantages.

A "receiving package" for cw bands from 160m to 15m is a solid-state receiver, consisting of a single-conversion tunable i.f. covering the lower portion of the 160m band, with converters for each additional band built in to the same package. Its small size, light weight and low power consumption make it an ideal portable receiver of quality. The use of separate converters for each band obviates complicated band switching, which is replaced by dc and 50Ω circuit switching.

A 160m amplifier for use with a 50–100W exciter for cw and ssb, fan-cooled, with 2,600V anode supply, will have a limited interest for British amateurs, and is in contra-distinction to a "direct conversion kilogram" for 20 and 40m, covering the reception of the cw portion of these bands. It is a companion to the 10W solid-state transmitter described in Chapter 6 (and in the 1974 edition). The receiving "kilogram" has a total power consumption of 0·6W and battery operation is practical; it has a size of only 6 by 7 by 3in and weighs 1kg, so it is attractive for portable work. A "circuit overview" of 11 lines, preceding a circuit description, is surely being self-critical to an unnecessary degree. The receiver looks a worthy mate for the advanced-design QRP transmitter in Chapter 6.

The rf speech clipper in the ssb transmission chapter is replaced by an audio speech processor which consists of a microphone preamplifier, high-pass filter, logarithmic amplifier, low-pass filter and a processed signal amplifier. The near elimination of hum, rf feedback and impedance matching problems by using audio processing instead of rf clipping makes this method more attractive, especially as it connects simply between microphone and transmitter input. Only a very small degree of distortion is the claim, together with ease of setting the proper level to the exciter, especially if the transmitter alc voltage can be monitored.

An outboard transverter for 1·8MHz is new. It is for owners of five-band transceivers and requires 1W of drive power at either 21 or 28MHz. The pa stage, a pair of 6146Bs operating in Class AB1, will deliver more than 100W p.e.p. output; an economy power supply to suit is described, and also details of the receiver operation.

Also new is a QRP ssb/cw transmitter for 80 or 20m. It is solid-state throughout and each version can deliver up to 9W p.e.p. into a 50Ω load. A regulated 12V dc supply of up to 2A is required.

A simple coupler for balanced lines is described, and a Unimatch, which is designed to couple energy from a 50Ω transmitter to any low-impedance load.

The treatment of ground-plane aerials has been revised, and a table of coil and dimension data is given. Limited-space aerials receive further attention, and there is a new short 20m 3-element Yagi and a 3-band quad, the latter being only 35ft above ground.

This publication continues to be a really practical encyclopaedia of amateur radio, and an inspiration to technically-minded people.

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